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Determinants of Public Spending Efficiency in Colombia's Water and Sanitation Sector

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Fragmentation, Scale, and Management: Determinants of Public Spending Efficiency in Colombia's Water and Sanitation Sector *

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Abstract

Achieving universal and equitable access to water and sanitation remains a critical challenge in Latin America and the Caribbean (LAC). This paper assesses the efficiency of public spending in providing water and sanitation services across Colombian municipalities. Efficiency levels are estimated using a stochastic frontier analysis that accounts for unobserved heterogeneity. The results show that the organizational and governance characteristics of service providers play a significant role in shaping spending efficiency. Municipalities with more service providers tend to be less efficient. In contrast, efficiency improves when providers operate across multiple jurisdictions. Additionally, municipalities where the head of the service provider is appointed–rather than elected–demonstrate greater efficiency. Overall, the findings indicate that public expenditures could be reduced by approximately 18% without compromising service quality, highlighting the potential for substantial gains through improved provider organization and governance.

JEL Codes: H42, H54, H72, L95.

Keywords: Water and sanitation services; Public spending efficiency; Stochastic frontier analysis.

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1 Introduction

Achieving universal and equitable access to safe and affordable water and sanitation by 2030 is essential for sustainable development, as outlined in Sustainable Development Goal (SDG) targets 6.1 and 6.2. While significant progress has been made globally, numerous challenges remain. For example, in 2015, approximately 96% of the population in the Latin America and Caribbean (LAC) region had access to at least a basic drinking water service. However, a much smaller percentage–only 75%–benefited from a safely managed drinking water service, a figure that has stagnated (WHO & UNICEF, 2023). Access disparities also exist when comparing water access to sanitation access, as well as between urban and rural areas, and other regional differences. In this context, Colombia, known for being one of the most unequal countries in LAC, exemplifies these challenges.

In Colombia, water supply coverage stands at 88.9%, yet sewage coverage lags, reaching only 75.4%. Disparities between urban and rural areas are stark, as urban locales boast nearly universal water supply coverage of 97.8% as of 2022, compared to a mere 58.6% in rural regions. A similar trend is observed in sewage services, where urban areas surpass their rural counterparts by a substantial margin of 78.4 percentage points. Furthermore, disparities in economic development across territories exacerbate these inequalities. For example, Bogotá, the nation's capital, has a coverage rate of approximately 99.6% for water and 99.1% for sewage services, whereas historically marginalized regions such as Chocó report significantly lower rates, with only 41.1% coverage for water and 21.8% for sewage services.

To achieve the above-mentioned SDG targets, it is essential to underscore the critical role of the public sector in the water and sanitation sector, particularly in light of several market failures, such as the presence of imperfect competitive markets characterized by increasing returns to scale, the existence of externalities, and asymmetries of informa-

tion. In this context, public intervention (financing, sector regulation, ownership, or fiscal mechanisms like subsidies) becomes imperative to address these market failures and bridge the water and sanitation gap. Given the constraints of limited public resources and the prevailing water and sanitation deficit, this paper aims to analyze the efficiency of public spending in providing water and sanitation services. To do so, we construct a database of 598 municipalities comprising information on public expenditure on the water and sanitation sector, coverage and service quality, and characteristics related to the management of these services. From an empirical strategy point of view, we assume that public expenditure is the cost required to produce water and sanitation services, and we use a stochastic frontier approach to estimate the (in)efficiency level. In particular, we use the True Random Effect (TRE) model proposed by Greene (2005) and Greene, Kumbhakar, and Lovell (2003) to control for unobserved time-invariant heterogeneity across municipalities. Moreover, not only we measure the efficiency in public spending, but we also identify a set of factors that may affect it.

Service provision depends on two types of expenditures: capital investment and recurrent expenditures related to the management and operation of service providers. In Colombia, subnational fiscal rules guarantee a minimum level of investment spending, and earmarked transfers for health, education, water, and sanitation have been in place since the early 1990s (Carreri and Martinez, 2024). This results in limited variation in infrastructure expenditure across municipalities, which may not be the binding constraint in many cases. Therefore, we focus on testing variables related to the characteristics of service providers. Specifically, we test three hypotheses. First, we hypothesize that a greater number of water service providers operating within the same municipality reduces public spending efficiency. This hypothesis builds on coordination theory and the fragmentation literature (Bel and Mur, 2008; Bel and Mur, 2009; Boetti, Piacenza, and Turati, 2012). Second, we hypothesize that municipal public spending efficiency is higher when water and sanitation service providers operate across multiple jurisdictions, relative to providers serving only a

single municipality. This hypothesis derives from economies of scale theory, suggesting that multi-jurisdictional providers achieve greater operational efficiency through larger service portfolios and enhanced professional capacity (Ferro, Lentini, and Mercadier, 2011; Pollitt and Steer, 2012). Third, we hypothesize that efficiency increases when the head of the service provider is not elected, as appointed managers may face fewer political constraints and can focus on technical and operational objectives rather than electoral considerations (Ruggiero, Duncombe, and Miner, 1995).

Our findings suggest that, despite relatively high levels of efficiency compared to benchmarks in other sectors operating under less structured institutional environments, there remains substantial room for efficiency gains in Colombia's water and sanitation sector. Specifically, we estimate that public expenditures could be reduced by approximately 18% without compromising the current levels of access to quality water and sanitation services. This efficiency gap is particularly salient given that universal access has yet to be achieved. These results underscore the importance of improving efficiency in public investment and service delivery mechanisms.

2 Background

In Colombia, access to drinking water and sanitation is recognized as a fundamental right. Article 366 of the 1991 Constitution (Colombia, 1991) and Law 142 of 1994 establish the State's obligation to ensure the fulfillment of basic needs, including access to potable water and sanitation. These legal provisions prioritize public spending on water supply–alongside education, health, and environmental sanitation–over other types of expenditures (Alesina, Carrasquilla, and Steiner, 2002). Law 142 further reinforces the State's role as the guarantor of public service provision, including water and sanitation.[1]

[1] Although it is the government's responsibility to ensure the provision of the service, Law 142 opened the possibility for mixed and private capital to participate in its provision.

The financing of drinking water and sanitation services in Colombia is embedded in a complex institutional framework characterized by multiple actors and diverse funding streams. These funding sources can be categorized into five main groups. First, national government resources, including allocations from the General Budget of the Nation (*Presupuesto General de la Nación, PGN*), channeled through entities such as the Ministry of Housing, City and Territory, the Presidency, the National Planning Department (DNP), Regional Autonomous Corporations (CARs), and Findeter. Second, CAR resources, which are allocated directly by the CARs themselves. Third, Public Service Provider (ESP) resources, consisting of internally generated funds. Fourth, special funds, such as the *Todos Somos Pazcífico* fund, are administered by the national government and the National Risk Management Unit (UNGRD). Finally, municipalities rely primarily on three main revenue sources: local tax and non-tax revenue (including property taxes, business receipt taxes, fines, and fees), transfers from the central government through the *Sistema General de Participaciones* (SGP), and royalties from the *Sistema General de Regalías* (SGR). While municipalities enjoy discretion over their own revenues, transfers are largely earmarked for specific services, including education, health, water, and sanitation, and there have been fiscal rules at the subnational level since the early 1990s (Martínez, 2023).

These resources support a range of initiatives aimed at expanding coverage and improving the quality of water and sanitation services. Key programs are the *Planes Departamentales de Agua* (PDAs), which serve as intermediaries between the national government and municipalities. Funded through multiple channels, PDAs are designed to enhance institutional coordination and promote regionalization of service provision, thereby improving efficiency.

While resource allocation is relatively centralized, execution is highly decentralized. In most cases, funds are executed directly by public service providers (ESP) or through municipal governments in collaboration with these providers. Exceptions arise when resources

originate from national or territorial budgets or from the *Todos Somos Pazcífico* fund, in which case execution may fall to departmental governments or other higher-level territorial entities.

Within this decentralized framework, public service providers (ESPs) and municipal governments play a central role in service provision and resource execution. Under Law 142 of 1994, municipalities may provide services directly or through public, private, or mixed-capital companies. It is common for a single provider to offer both water and sanitation services.

Service provision arrangements vary widely. Some companies operate across multiple municipalities, while others serve only a single locality. It is also common for several providers to coexist within the same municipality. Providers vary widely in scale—from small community associations serving fewer than 5,000 users to large utilities managing services for over one million users—as well as in capacity, including their ability to manage resources and comply with basic standards for delivering quality service (Castillo-Castillo, El-Khattabi, and Fernandez, 2025).

To navigate this complex landscape, the Colombian government established the Commission for the Regulation of Drinking Water and Basic Sanitation (CRA) under Law 142 of 1994. The CRA supports the development of a regulatory and institutional framework that promotes efficient service delivery. Among its core responsibilities is the establishment of pricing criteria for water and sanitation services.

3 Literature Review and Hypotheses

Our study contributes to several strands of the literature on public spending efficiency and water service provision. We contribute to the extensive body of work on public spending efficiency measurement, particularly at the local government level, which has gained renewed attention following economic crises and increasing demands for fiscal discipline (International Monetary Fund, 2015; Milán-García, Rueda-López, and De Pablo-Valenciano, 2022). While most efficiency studies focus on input-output relationships and traditional determinants such as population size and financial resources (Da Cruz and Marques, 2014; Narbón-Perpiñá and De Witte, 2018), our work extends this literature by examining how the structure of service provision–specifically the number, geographic scope, and management of water service providers–affects municipal spending efficiency. Our study focuses on local government efficiency while incorporating the institutional arrangement of service providers as a key determinant. Second, our research contributes to understanding efficiency determinants in contexts with strong institutional frameworks, contrasting with studies that emphasize income sources and fiscal capacity as primary drivers (Martínez, 2023; Carreri and Martinez, 2024).

The literature on public spending efficiency has established that efficient resource use is fundamental for achieving sustainable development outcomes and maximizing the impact of government investment (International Monetary Fund, 2015). Water and sanitation service provision, as well as other government services, is the result of combining multiple elements: the existing infrastructure and ongoing expenditures. Efficient service provision requires not only adequate infrastructure investment but also effective management of operational and maintenance expenditures. Depending on the data available, the literature on public spending efficiency makes a clear distinction between investment and current expenditure, although this distinction, while conceptually clear, is not always empirically straightforward to implement. Efficiency in public spending is typically assessed using a production

function framework, wherein government expenditures are used to generate outputs such as health, education, and water services, conditional on a given technology. The production function defines the efficiency frontier, and the deviation of an observation–whether by a central or local government–from this frontier serves as a measure of inefficiency. Within this theoretical construct, empirical studies predominantly employ two methodological approaches: parametric techniques, notably Stochastic Frontier Analysis (SFA), and nonparametric techniques, particularly Data Envelopment Analysis (DEA). Each method offers distinct advantages in estimating efficiency and benchmarking performance.

Moreover, analyses of public spending efficiency have been conducted at both national and subnational levels, and from both cross-sectoral and sector-specific perspectives (Milán-García, Rueda-López, and De Pablo-Valenciano, 2022). Empirical evidence reveals substantial efficiency gaps across countries and sectors. The IMF's analysis demonstrates that average inefficiencies in public investment processes reach approximately 30 percent, with the most efficient public investors achieving twice the growth impact per investment dollar compared to the least efficient (International Monetary Fund, 2015). This efficiency gap is particularly pronounced in developing countries, where institutional weaknesses in project selection, management, and evaluation compound resource constraints (Gupta et al., 2014). Studies using efficiency-adjusted public capital measures show that while the share of public capital may be smaller in low-income countries, the marginal product of public capital is relatively large due to lower baseline efficiency-adjusted capital stocks, highlighting the critical importance of efficiency improvements in resource-constrained environments.

The literature emphasizes that institutional quality serves as a fundamental determinant of efficiency outcomes. Countries with stronger public investment management institutions demonstrate more predictable, credible, efficient, and productive investments, with the Public Investment Management Assessment (PIMA) framework identifying 15 key institutions that shape planning, allocation, and implementation processes (International Monetary

Fund, 2015). Research on fiscal rules and governance mechanisms shows that institutional frameworks can significantly enhance efficiency by improving accountability and reducing waste, particularly at the local government level, where service delivery directly impacts citizens (Carreri and Martinez, 2024). These findings underscore that efficiency is not merely a technical optimization problem but fundamentally depends on the institutional environment governing resource allocation and utilization decisions.

Research on local government water efficiency examines how institutional arrangements and service delivery structures can influence efficiency. Barde (2017) demonstrates that community-based water systems can outperform government-managed systems in rural Brazil, achieving higher access rates through enhanced accountability mechanisms and local engagement. This finding suggests that the structure of service provision can be an important efficiency determinant. Similarly, studies examining different ownership models and organizational arrangements indicate that the institutional framework governing service delivery significantly affects efficiency outcomes (Peda, Grossi, and Liik, 2013; Warner, 2013).

The literature on efficiency determinants provides a comprehensive framework for understanding factors that influence local government performance. However, traditional categorizations may not fully capture the institutional complexities of service provision arrangements. Da Cruz and Marques (2014) and Mergoni and De Witte (2022) classify efficiency determinants into five categories: geographical and natural factors (climate, topography), political determinants reflecting citizen behavior and preferences, institutional determinants encompassing organizational capacity and behavior, financial determinants related to investment levels and fiscal constraints, and economic determinants capturing local economic conditions. While this framework has proven useful for analyzing efficiency variations across jurisdictions, it primarily focuses on characteristics of individual governments rather than the structure of service delivery arrangements.

Recent research has begun to recognize that the organization of service provision itself constitutes a critical efficiency determinant that transcends traditional categorizations. Warner (2013) demonstrates that local government size affects the optimal choice between direct provision, privatization, and hybrid service delivery models, with suboptimal size occurring both when governments are too small to realize scale economies and too large to maintain competitive pressure. This insight suggests that efficiency depends not only on municipal characteristics but also on how services are organized and delivered. Barde (2017) provides empirical evidence that service delivery structure matters significantly, showing that community-based water systems achieve better outcomes than government-managed systems through enhanced accountability mechanisms, higher public awareness, and improved local oversight.

The service provision structure literature reveals potentially competing effects on efficiency across multiple dimensions. On the one hand, coordination costs and fragmentation may increase when multiple providers serve the same jurisdiction, as overlapping responsibilities can lead to duplicated administrative functions, reduced economies of scale in procurement and management, and weakened accountability structures (Warner, 2013). On the other hand, providers operating across multiple jurisdictions may achieve greater efficiency through scale economies, knowledge spillovers, and enhanced professional capacity that comes with managing larger service portfolios (Barde, 2017). Additionally, the governance structure of service providers may affect efficiency outcomes (Salazar-Adams, 2021).

Our analytical framework builds on this literature by proposing that service provision structure–specifically, the number of providers within a municipality and whether providers operate across multiple jurisdictions, and the specialization of the manager of the provider–represents a distinct category of efficiency determinant that operates through coordination and scale mechanisms. This approach extends beyond traditional determinant frameworks

by recognizing that institutional arrangements for service delivery can independently affect efficiency outcomes, even when controlling for municipal characteristics, financial resources, and governance quality. The Colombian institutional context provides an ideal setting for testing these relationships, as fiscal rules and earmarking requirements control for many traditional efficiency determinants, allowing us to isolate the effects of service provision structure on municipal spending efficiency (Carreri and Martinez, 2024; Martínez, 2023).

Unlike most developing countries, where revenue sources and fiscal management practices vary substantially across municipalities, Colombia's institutional design systematically addresses the financial and managerial factors that dominate the efficiency literature. In Colombia, royalty allocation rules require 75% of natural resource revenues to be spent on priority areas, including water and sanitation, until specific coverage targets are met–91.5% for drinking water access and 85.5% for sewerage coverage. This earmarking mechanism ensures that funding for water services is largely predetermined rather than subject to municipal discretion, effectively controlling for the revenue source effects that typically drive efficiency variations across jurisdictions. In fact, Martínez (2023) shows that a windfall of royalties is largely spent on water and sanitation.

Furthermore, Carreri and Martinez (2024) shows that Colombia's fiscal rules, which cap municipal operating expenditures at 80% of current revenue, create strong enforcement mechanisms that improve efficiency by reducing waste in public administration. These rules are enforced by national oversight agencies with real sanctions for non-compliance, including loss of access to central government financial support and personal disciplinary measures for municipal officials. This institutional framework ensures that fiscal management practices are standardized across municipalities, removing another primary source of efficiency variation identified in the international literature. The combination of earmarked funding and enforced fiscal discipline implies that traditional determinants–such as fiscal capacity, revenue-generating ability, and the quality of financial management–are not decisive factors

in the provision of water and sanitation services.

In this controlled institutional environment, we propose that service provision structure emerges as a critical efficiency determinant that operates independently of financial and managerial factors. Based on the theoretical mechanisms identified in the literature and the specific characteristics of Colombia's water sector, we formulate two primary hypotheses:

Hypothesis 1: *The higher the number of water and sanitation service providers operating within the same municipality, the lower the public spending efficiency.*

This hypothesis builds on coordination theory and the fragmentation literature, which suggests that multiple providers create coordination costs, duplicate administrative functions, reduce economies of scale in procurement and management, and weaken accountability structures (Warner, 2013).

Hypothesis 2: *Municipal public spending efficiency is higher when water service providers operate across multiple jurisdictions, relative to providers serving only a single municipality.*

Multi-jurisdictional providers can achieve greater operational efficiency through larger service portfolios, enhanced professional capacity, improved technology adoption, and better resource utilization across their service areas. Additionally, such providers may face stronger performance incentives due to reputation effects across multiple jurisdictions and may benefit from reduced political interference that often affects single-municipality providers.

Hypothesis 3: *Municipal public spending efficiency is higher when water service providers are managed by appointed technical personnel rather than elected officials.*

This hypothesis derives from public administration theory and the literature on political interference in public service delivery, which suggests that selected managers face competing

incentives between technical efficiency and electoral considerations (Salazar-Adams, 2021). Appointed technical managers can focus primarily on operational efficiency, service quality, and cost-effective resource allocation without the need to consider electoral cycles or political patronage.

These hypotheses are particularly testable in the Colombian context because the institutional framework controls for the alternative explanations that typically confound service structure effects. The earmarking of royalty revenues for water services means that funding availability is not driving efficiency differences, while fiscal rules ensure that municipal management capacity is relatively standardized. This allows us to isolate the pure effects of service provision arrangements on efficiency outcomes, providing a cleaner test of how organizational structure affects public service delivery than would be possible in contexts where financial and institutional factors vary freely across jurisdictions.

4 Empirical Strategy

We model public spending as a cost function, where public expenditure is required to produce water and sanitation services in municipality (i) during time period (t):

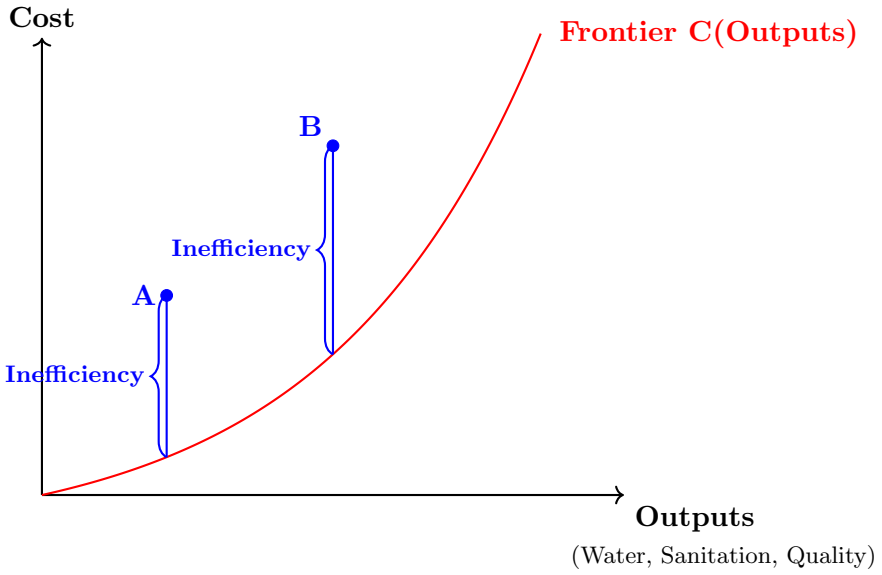
$$C_{it} = f(X_{it}, PSE_{it}) \tag{1}$$

In this equation, C_{it} denotes the public expenditure for municipality i in time period t; X_{it} is a vector of cost drivers, including input prices and water and sanitation outputs; and PSE_{it} represents the level of Public Spending Efficiency.

To estimate public spending efficiency, we employ the stochastic frontier approach introduced by Aigner, Lovell, and Schmidt (1977). The cost frontier function identifies the minimum public expenditure required to produce water and sanitation services in a given municipality and time period. This method enables us to determine whether a municipality

operates on the efficiency frontier. If a municipality is not on the frontier, the distance to the frontier quantifies the level of public spending inefficiency.

Figure 1: Stochastic Frontier Approach



From an econometric point of view, and given our data, we need to consider panel data methods to estimate the stochastic frontier model, such as the panel data version of Aigner, Lovell, and Schmidt (1977) proposed by Pitt and Lee (1981):

$$ln(C_{it}) = \alpha_i + \beta ln(X_{it}) + \epsilon_{it} \tag{2}$$

where C_{it} represents the public expenditure received by municipality i and time period t; X_{it} is a vector of cost drivers including input prices and water and sanitation outputs; β is the vector of coefficients to estimate; and ϵ_{it} is an error term that can be decomposed into two components, such that $\epsilon_{it} = u_{it} + v_{it}$, being v_{it} the idiosyncratic error term, assumed to be normally distributed, and u_{it} a one-sided non-negative error term representing the inefficiency.

However, this model does not control for unobserved time-invariant heterogeneity across municipalities, which may affect the production of water and sanitation access. The True

Random Effects (TRE) model proposed by Greene (2005) and Greene, Kumbhakar, and Lovell (2003) extends the model by including a term for time-invariant unobserved heterogeneity:

$$\begin{aligned} ln(C_{it}) =& \alpha_i + \beta ln(X_{it}) + \epsilon_{it} \\ \epsilon_{it} =& v_{it} + u_{it} \\ \alpha_i =& \alpha + w_i, w_i \sim N(0, \sigma_w^2) \\ v_{it} \sim& (0, \sigma_v^2) \\ u_{it} =& |U_{it}|, u_{it} \sim N(0, \sigma_u^2) \end{aligned} \tag{3}$$

where w_i is the random term controlling for the unobserved time-invariant heterogeneity.

Last, one may also consider the inclusion of exogenous variables, which are neither outputs nor input prices but can affect the distribution of inefficiency. As noted by Kumbhakar and Lovell (2003), the presence of uncontrolled unobservable heterogeneity in u_{it} and v_{it} can impact inference in SF models. Therefore, we examine the role of a set of determinants on inefficiency by scaling its distribution:

$$\begin{aligned} u_{it} =& |U_{it}|, u_{it} \sim N(0, \sigma_u^2) \\ \sigma_{u_{it}}^2 =& exp(\psi z_{it}) \end{aligned} \tag{4}$$

4.1 Data

Our analysis is based on an unbalanced panel data set for a sample of 598 municipalities in Colombia for the period 2010 - 2021[2]. We get annual municipal-level data on public spending for water and sanitation from the Superintendency of Residential Public Services

[2] According to the National Administrative Department of Statistics (*Departamento Administrativo Nacional de Estadísticas* DANE), there are 1,104 municipalities in Colombia.

(*Superintendencia de Servicios Públicos Domiciliarios* SSPD). We collected information about the quality of the water service from the Water Quality Risk Index (IRCA) that is published by the National Institute of Health (*Instituto Nacional de Salud* INS) annually at the municipal level. We gathered municipal-level annual rates of water and sewage access from *Terridata*, managed by the National Planning Department (*Departamento Nacional de Planeación* DNP). Additionally, we integrated four supplementary environmental variables from the SSPD, the National Administrative Statistics Department (*Departamento Administrativo Nacional de Estadística* DANE), and the Center for Economic Development Studies (*Centro de Estudios de Desarrollo Económico* CEDE).

Our dependent variable, i.e., the measure of cost used to produce access to quality water and sanitation, is *Total public spending*, which represents the total amount each municipality allocates to water and sanitation services, covering areas such as new infrastructure, maintenance and repairs, subsidies, administrative expenses, and the Water Departmental Plans (*Planes Departamentales de Agua* PDA).

As outputs, we include two variables measuring access to drinking water via water treatment plants (*Water access*) and sewage coverage (*Sewage access*), respectively. The underlying data–collected initially by the Superintendency of Residential Public Services (*Superintendencia de Servicios Públicos Domiciliarios* SSPD) and cleaned by the National Planning Department (*Departamento Nacional de Planeación* DNP)–is compiled in the "Coverage and Stratification Report," which details the water and sewage connections reported by all the companies in each municipality.

We also consider a measure of drinking water quality, derived from the Water Quality Risk Index (*Índice de Riesgo de Calidad del Agua* IRCA), which assesses the risk of drinking water contamination based on physical, chemical, and microbiological attributes. The Colombian government calculates this index through the National Health Institute (*Insti-*

tuto Nacional de Salud INS). The IRCA index is constructed as follows (Martínez-García, Jaramillo-Colorado, and Fernández-Maestre, 2019):

$$IRCA = \frac{\text{Risk score for unacceptable parameters}}{\text{Risk score for all parameters considered}} \times 100 \tag{5}$$

This variable takes values from 0% to 100%, where 0% represents water without risk and 100% represents water that is not sanitarily viable.

Following the standard efficiency literature, we account for environmental variables that influence inefficiency but lie outside the control of the decision-making unit, such as managerial attributes or internal governance structures. In this context, we introduce three variables capturing organizational characteristics relevant to public spending in the water and sanitation sector. First, we include the total number of utilities providing water and sanitation services within each municipality (*Total utilities*), which proxies for market fragmentation and potential coordination challenges. Second, we consider the number of municipalities served by the utility with the largest consumer base in the municipality (*Total municipalities*), reflecting the scale and geographic scope of service provision. Third, we construct a variable measuring the share of the municipal population served by a utility in which the politician holds a managerial role (*Politician*), capturing potential political influence over operational decisions. These variables are used to test the hypotheses outlined in Section 3. In addition, we include two control variables which can be associated with efficiency outcomes: the share of the municipal population residing in rural areas (*Rural*) and the share of the population served by a private water utility (*Private*).

Table 1: Variable definition and sources

Use in model	Variable	Source	Description	Unit
Cost	*Total public spending*	SSPD (2024)	Expenditure made for water and sanitation services by each municipality	Billions of Colombian pesos
Outputs	*Water access*	Terridata DNP (2024)	Population connected to water treatment plant services	Number of people
	Sewage access	Terridata DNP (2024)	Population connected to sewage services	Number of people
	*Water quality (*IRCA)	INS (2024)	Index that weights physical, chemical, and microbiological characteristics of water	Index from 0 to 100
Environmental variables	*Property tax %*	CEDE (2024)	Share of property tax revenue in total municipal income	Colombian pesos
	Total utilities	SSPD (2024)	Number of total companies providing water and sewage service in each municipality	Ordinal number
	Total municipalities	SSPD (2024)	Number of municipalities served by the utility with the largest consumer base	Ordinal number
	Politician	SSPD (2024)	Share of the municipal population served by a utility in which a politician holds a managerial role	Percentage
	Rural	CEDE (2024)	Share of the municipal population residing in rural areas	Percentage
	Private	SSPD (2024)	Share of the municipal population served by a private utility	Percentage

Notes: There are 6 mandatory characteristics that must be reported for all municipalities for the estimation of the Water Quality index (IRCA). These characteristics and their units are: Turbidity (Nephelometric Turbidity Units *NTU*), Colour (Platinum-cobalt color *Pt-Co*), Coliforms (1 count/100ml), E-coli (1 count/100ml), pH, and Free Residual Chlorine (mg/L) (Protección Social and Ambiente, 2007).

Table 2: Descriptive statistics

	Mean	Std. Dev.
Total public spending (log)	18.29	1.16
Water access (log)	13.62	1.44
Sewage access (log)	13.20	1.64
Water quality (IRCA) (log)	2.24	1.54
Property tax % (log)	-3.36	1.18
Total utilities	1.31	1.06
Total municipalities	3.86	7.56
Politician	23.64	41.95
Rural	53.88	23.75
Private	44.13	48.75

Notes: 5,998 observations. *Total public spending* refers to annual municipal-level expenditures on water and sanitation services, including infrastructure, maintenance, and subsidies, administrative expenses, and the Water Departmental Plans (Planes Departamentales de Agua PDA), sourced from the SSPD. *Water access* and *Sewage access* measure the percentage of households connected to the respective services and are obtained from Terridata–DNP. *Water quality (IRCA)* is derived from the IRCA index published by INS, ranging from 0 (no risk) to 100 (unsafe water). *Property tax %* is the share of property tax revenue in total municipal income. *Total utilities* denotes the number of providers in each municipality, and *Total municipalities* reflects the number of municipalities served by the largest utility.

5 Results

5.1 Descriptive Evidence of Public Spending and Outputs

Public spending in the water and sanitation sector in Colombia exhibited a relatively stable trend over the 2011–2020 period, with average spending levels remaining consistent across years. However, this apparent stability masks a growing heterogeneity in spending patterns across municipalities, as evidenced by the increasing dispersion shown in Figure 2.

A closer examination of per capita public spending reveals a negative correlation with population size: smaller municipalities tend to execute higher per capita spending than their

more populous counterparts. This pattern is consistent with the presence of diseconomies of scale in service provision, where fixed infrastructure and administrative costs are spread over a smaller population base. Moreover, the distribution of per capita spending is markedly more dispersed among smaller cities (Figure 3), indicating potential substantial variation in local fiscal capacity, institutional efficiency, or both.

Figure 2: Evolution of Total Public Spending in the Water and Sanitation Sector

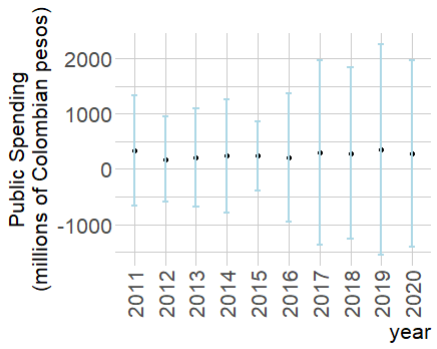
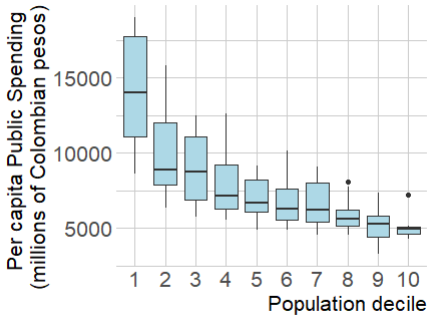


Figure 3: Per Capita Public Spending in the Water and Sanitation Sector



Examining the outputs associated with public spending over the period, we find that, as expected, access to drinking water consistently exceeds access to sanitation (Figure 4). While overall access levels remain relatively stable, a modest upward trend–particularly in the latter years–indicates incremental improvements. Given the constancy of public spending over the same period (Figure 2), these gains may reflect improvements in the efficiency of public expenditure.

Lastly, Figure 5 indicates an improvement in water quality over the period of analysis, as evidenced by a decline in both the mean and dispersion of the *Water Quality Risk Index*. This trend is particularly observed in the final three years of the sample. Since the index decreases as the share of water deemed sanitarily unviable declines, lower values reflect improvements in water safety and quality.

Figure 4: Evolution of Access to Water and Sanitation

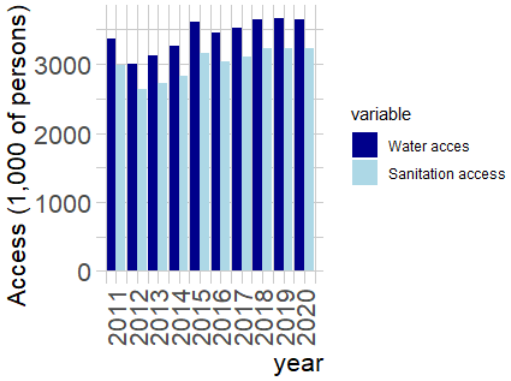
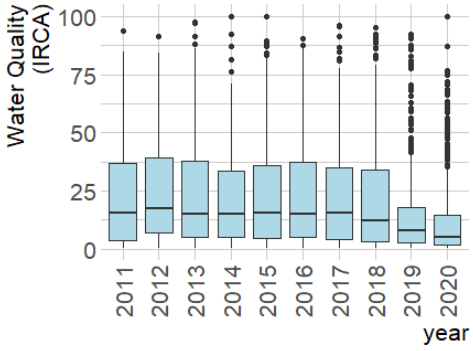


Figure 5: Evolution of the Water Quality Risk Index



5.2 Measurement of public efficiency spending

The estimation results for the models, both with and without the inclusion of efficiency determinants, are presented in Table 3. The coefficients are significant and exhibit the expected signs. Specifically, the coefficients for the population with access to water and sanitation and the one associated with the per capita property taxes, which is considered a proxy for input prices, are positive, while the coefficient for the water quality risk index is negative. A comparison of the two models reveals that the estimated coefficients are relatively similar.

Table 3: Estimation results

	log(Total Public Spending)	*log(Total Public Spending)*
log(Water access)	0.372***	0.372***
	(15.96)	(15.87)
log(Sanitation access)	0.119***	0.121***
	(5.77)	(5.82)
log(Water Quality (IRCA))	-0.0364***	-0.0353***
	(-4.84)	(-4.71)
log(Property taxes pc)	0.0436***	0.0413***
	(3.36)	(3.14)
Constant	11.56***	11.51***
	(64.54)	(63.43)
σ_u		
Total utilities		0.0772*
		(1.69)
Total municipalities		-0.0375***
		(-3.38)
Rural		-0.158
		(-0.55)
Private		0.00177
		(1.25)
Major		0.00289*
		(1.78)
Constant	-2.137***	-2.125***
	(-19.44)	(-10.10)
σ_v		
Constant	-1.384***	-1.402***
	(-29.39)	(-27.40)
σ_w		
Constant	0.535***	0.525***
	(30.50)	(29.21)
N	5998	5998

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The model allows for the estimation of economies of scale, defined as the elasticity of cost with respect to output. Since public spending and the explanatory variables are expressed in logarithmic form, the estimated coefficients can be directly interpreted as cost elasticities. Accordingly, a 1% increase in the population with access to water, holding all other variables constant, results in an increase in public spending of 0.372%. Similarly, public spending increases by 0.119% to 0.121% with a 1% increase in sewage access. Given the relatively high level of water access already achieved and the higher marginal cost associated with further expansion, it is likely that the remaining areas without access are those

that are more difficult and expensive to reach. In contrast, the lower cost elasticity observed for sewage access suggests that there is still significant room for expansion in areas where implementation may be less complex and more cost-effective. Furthermore, a 1% reduction in the risk of drinking water quality leads to an increase in public spending ranging from 0.0353% to 0.0364%.

In our multi-output context, overall economies of scale are defined as the proportional reduction in average cost resulting from a uniform increase in all outputs, holding input prices constant. This measure corresponds to the inverse of the sum of the cost elasticities with respect to each output. It is important to note that our water quality indicator ranges from 0% (no sanitary risk) to 100% (non-viable for consumption), such that improvements in quality are reflected as decreases in the variable's value. Accordingly, the expected relationship between water quality and cost is negative. To ensure consistency in the construction of the overall economies of scale metric, we use the absolute value of the partial derivative of the log of cost with respect to the log of water quality:

$$ES = \frac{1}{\frac{\delta log(C)}{\delta log(Wateraccess)} + \frac{\delta log(C)}{\delta log(Sanitationaccess)} + \left|\frac{\delta log(C)}{\delta log(Quality)}\right|} \tag{6}$$

Economies of scale are present when the ES exceeds one, indicating that average costs decline as output increases. Conversely, ES values below one reflect diseconomies of scale, where average costs rise with output. An ES equal to one implies constant returns to scale, with no cost advantages or disadvantages from scaling production. We find evidence of increasing returns to scale, with an ES of 1.89 across municipalities in our sample. This suggests that the average cost of delivering high-quality water and sanitation services declines as the number of beneficiaries within a municipality increases. These results are consistent with the descriptive patterns presented in Section 5.1 and illustrated in Figure 3. As noted by Ferro, Lentini, et al. (2010), Colombia introduced the PDAs as a strategic response to

persistent structural inefficiencies in the water and sanitation sector. These inefficiencies include a highly fragmented industry structure that limits the exploitation of economies of scale, disjointed financing mechanisms, weak planning and pre-investment processes leading to atomized and non-integrated investments, restricted access to credit, and slow progress in enterprise modernization. The PDA framework seeks to address these challenges by promoting the voluntary aggregation of municipal service providers into departmental enterprises, thereby enabling more efficient infrastructure use and coordinated investment planning. Empirical evidence supports the rationale behind this approach. Revollo and Londoño (2010) estimate cost functions for a sample of Colombian utilities and find robust evidence of economies of scale, particularly among small and medium-sized providers.

Regarding the efficiency determinants, the estimated coefficient for total utilities is positive and significant at 10% level. Consequently, we do not reject Hypothesis 1 as outlined in Section 3. This result is in line with Klien (2017) who analyzes the impact of water and sanitation utilities aggregation on a composite performance indicator, finding financial and managerial improvements after aggregation reforms. Conversely, the coefficient for total municipalities is negative and significant, suggesting that lower levels of public spending inefficiency are observed when the water utility with the largest consumer share in each municipality also operates in other municipalities. Thus, we do not reject Hypothesis 2. Last, the estimated coefficient for *Politician* is positive and significant at 10% level, suggesting that municipalities in which a politician assumes a managerial role in the water utility exhibit lower efficiency in public spending. As noted by Salazar-Adams (2021), in many cases, public utilities operate with limited external oversight, as their governance structures often include local political figures–such as mayors or state governors–who serve as board members or even chairpersons. This arrangement tends to politicize the appointment of utility directors, prioritizing political loyalty over technical expertise and blurring the boundaries between political leadership and utility management, which may result in inefficiencies.

The mean and standard deviation of the efficiency scores are presented in Table 4, with histograms illustrating the distribution of these scores shown in Figure 6. For the Colombian municipalities in our sample during the period 2010-2021, the mean efficiency score is 0.821 for the model excluding efficiency determinants and 0.823 for the model including them. These results suggest that public spending could be reduced by 17.9% or 17.7%, respectively, while maintaining the same level of outputs, i.e., water access, sewage access, and water quality. The mean efficiency scores observed exceed those typically reported in the literature on public spending efficiency, both at the national (International Monetary Fund, 2015; Afonso and Fraga, 2024) local (De Borger and Kerstens, 1996; Worthington, 2000) levels, where inefficiencies of approximately 30 percent are commonly found. One possible explanation for this result lies in Colombia's institutional design, which may constrain variation in fiscal management practices across municipalities. This institutional uniformity could reduce the deviations from the efficiency frontier. The evolution of the efficiency scores is shown in Figure 7, where we observe that the mean score is relatively stable over time, ranging approximately between 0.8 and 0.85, with a relatively constant dispersion around that mean.

We estimate that, on average, public spending in the water and sanitation sector could be reduced by approximately 2.73 billion Colombian pesos without compromising current levels of service coverage or quality. These potential savings are particularly relevant given that universal access has not yet been achieved and that, despite recent improvements, the water quality index continues to indicate instances where water remains unfit for human consumption. Accordingly, reallocating these efficiency gains toward expanding coverage and improving water service quality could accelerate progress toward universal and safely managed water and sanitation services.

Table 4: Descriptive statistics - Efficiency scores, Real and Efficient Public Spending, and potential savings

	Mean	Std. Dev.
Efficiency score - Model 1	0.821	0.087
Efficiency score - Model 2	0.823	0.085
Real Public Spending (in billions of pesos)	26.041	130.489
Efficient Public Spending (in billions of pesos)	23.315	121.604
Potential savings (in billions of pesos)	2.727	8.983

Figure 6: Efficiency Scores - Density

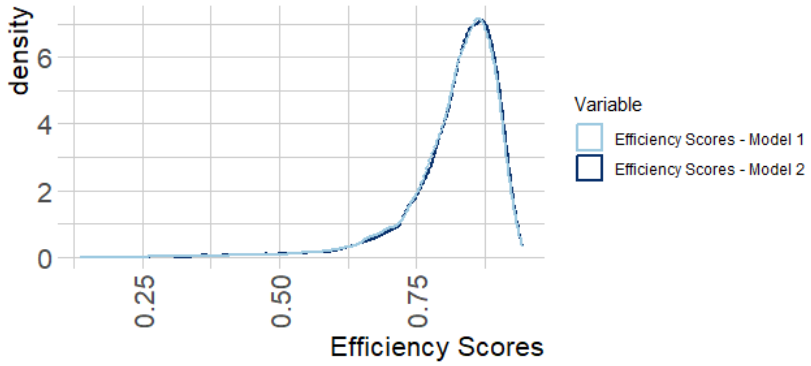
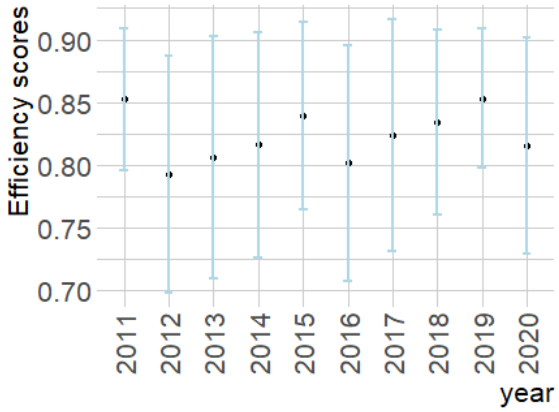


Figure 7: Evolution of Efficiency Scores



6 Conclusion

This paper evaluates the efficiency of public spending in Colombia's water and sanitation sector, a critical area for achieving Sustainable Development Goal targets 6.1 and 6.2. Despite relatively high average efficiency scores–exceeding those typically reported in the literature (Afonso and Kazemi, 2017)–our findings reveal that public expenditures could be reduced by approximately 18 percent without compromising current service levels. These

efficiency gains are particularly salient in a context where universal access remains elusive and regional disparities persist.

Our analysis confirms the relevance of the three key organizational characteristics proposed in the hypotheses as significant determinants of public spending efficiency. First, fragmentation in service provision–measured by the number of utilities operating within a municipality–is associated with lower efficiency, likely due to coordination challenges, administrative duplication, and reduced economies of scale. This finding aligns with previous studies that highlight the inefficiencies arising from fragmented governance structures (Grossman, Pierskalla, and Boswell Dean, 2017; Dowding and Mergoupis, 2003). Second, we find that utilities operating across multiple jurisdictions are significantly more efficient, consistent with the existence of economies of scale, greater managerial capacity, and improved resource allocation— an effect also supported by recent empirical evidence (Gómez-Reino, Lago-Peñas, and Martinez-Vazquez, 2023). Third, our results show that political interference, proxied by politician involvement in the management of utilities, is negatively associated with efficiency. This supports the view that politicized governance can hinder effective service delivery by distorting managerial incentives, as noted in prior research (Ruggiero, Duncombe, and Miner, 1995; Abrate et al., 2018).

These findings yield several policy implications. First, consolidation of service providers should be encouraged, particularly in municipalities with overlapping or fragmented utility structures. Regulatory frameworks could incentivize mergers or the creation of regional utilities to exploit scale economies. This is consistent with has been found previously in similar studies for Colombia (Castillo-Castillo, El-Khattabi, and Fernandez, 2025). Second, institutional arrangements that promote professionalized, non-political management of utilities should be prioritized. This may include reforms to utility governance boards, merit-based appointments, and enhanced oversight mechanisms (Curry, 1999). Third, while Colombia's earmarked transfers and fiscal rules have contributed to relatively uniform investment lev-

els, future reforms should focus on improving the quality and efficiency of spending rather than increasing its volume.

Finally, the presence of increasing returns to scale suggests that expanding service coverage–particularly in underserved rural and marginalized regions–can yield cost efficiencies. Targeted investments that extend access while leveraging existing infrastructure could therefore enhance both equity and efficiency. These insights are directly relevant for policymakers seeking to close the water and sanitation gap under fiscal constraints, and they offer a framework for similar analyses in other countries facing comparable challenges.

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